Shallow Water Optics Data Analysis and Modeling

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LONG-TERM GOALS

The overall goal of this project is to characterize the spatial and temporal variability of spectral bottom reflectance and the boundary layer of water just above the bottom in optically shallow coastal environments of various bottom types. By measuring ambient, spectral light-field quantities as they change temporally, along with water-column IOP's and other environmental parameters, we hope to achieve a deeper understanding of radiative transfer in optically shallow waters that can be applied to problems in bottom-type classification, optical bathymetry, hyperspectral remote sensing, and benthic productivity.

OBJECTIVES

In this program we are attempting to fully characterize the spectral irradiance reflectance of a variety of bottom types in optically shallow waters, with simultaneous measurements of remote-sensing reflectance and water-column IOP's. One of our objectives is to measure bottom reflectance with both moored and diver-operated hyperspectral radiometers to obtain both daily time series and synoptic measurements of specific areas. The moored time series will tell us something about the temporal variability in bottom reflectance (and apparent bottom reflectance as measured from the surface) due to biological migrations and changing environmental conditions and forcing mechanisms such as wind and waves, tides, subsurface currents, and solar insolation. The synoptic, diver measurements will tell us something about the spatial variability in bottom reflectances.

Conducting this investigation requires new instruments and methods. Thus another objective is to develop a new type of spectrometer system that is highly versatile and accurate. Our design objectives for this hyperspectral radiometer system, which we call HydroRad, include the ability to measure both bottom and surface reflectance in a moored configuration, ability to be diver deployed for measuring bottom reflectance, and the ability to be ship deployed for measuring remote-sensing reflectance. Related to this objective is to develop shallow-water optical models that can be tested with HydroRad measurements and with additional measurements of water-column IOP's.

APPROACH

Our approach to characterizing and quantifying the spectral bottom reflectance, remote-sensing reflectance, and their changes in time and space, is to develop and use a new type of hyperspectral radiometer system. We chose to incorporate miniature fiber-optic spectrometers in a sealed pressure

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housing, coupled with underwater fiber-optic cables and light collectors which provide great versatility in configuring the system, called HydroRad, to make moored, diver operated, or shipboard measurements of hyperspectral light-field quantities (i.e., radiance, plane irradiance, and scalar irradiance). By deploying several HydroRads (six at LSI during the May 2000 experiment), we could measure bottom reflectance and surface remote-sensing reflectance (RSR) at several sites simultaneously, which was especially useful during the PHILLS overflights.

In addition to the hyperspectral measurements of bottom reflectance and RSR, our scientific goals require data on the IOP's of the water. To make these measurements at the HydroRad moorings we used HOBI Labs a-beta, c-beta, and HydroScat-2 instruments. These instruments, which are fully self-contained and hence exceptionally easy to use on moorings, allowed us to collect time-series of absorption, backscattering, and attenuation coefficients of the water. Figure 1 shows a photograph of one of the HydroRad moorings, showing the variety of instruments and measurements that were used to obtain time-series of the optical properties of the benthic environment. Figure 2 shows the HydroRad-tethered surface buoy for making RSR measurements. Figure 3 shows an aerial photograph of the closure study site with red crosses marking the locations of the HydroRad moorings. We also conducted synoptic optical surveys of the study area around LSI using a small boat, taking measurements of the water column and bottom reflectance with a diver operated HydroRad.

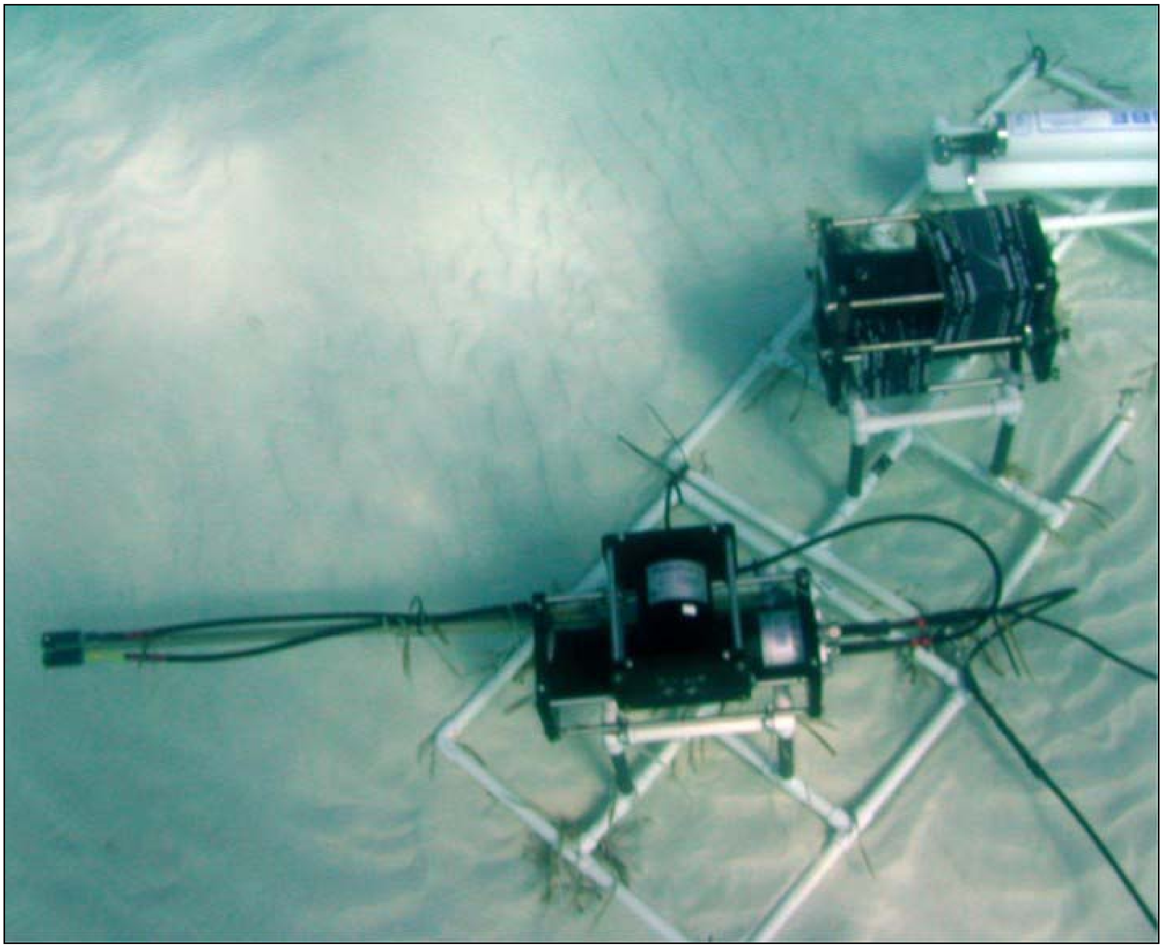

Figure 1. Underwater photograph of one of the HydroRad moorings at LSI in May 2000. Bottom of photograph shows the HydroRad with a HydroScat-2 mounted on top. The wand sticking out to the left has upwelling and downwelling irradiance collectors attached for measuring bottom reflectance. The instrument package in the middle of the photograph consists of a HOBI Labs a-beta and c-beta, and a wave-tide gauge is shown at the top of the photo. A buoy (not shown) is tethered at the surface for measuring remote-sensing reflectance.

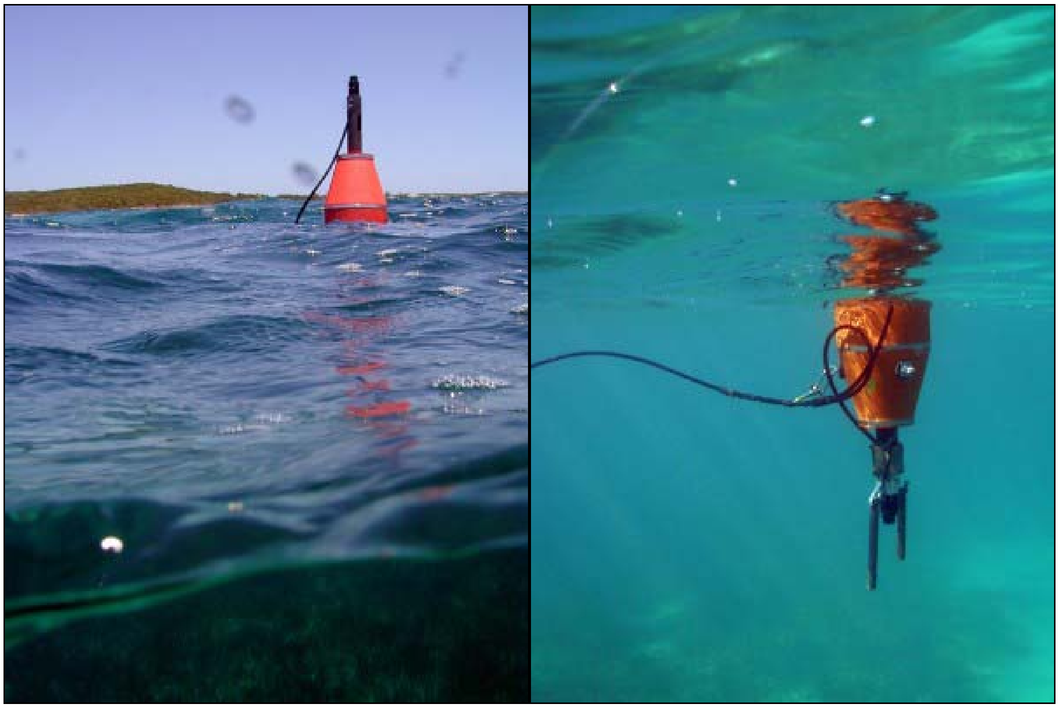

Figure 2. Above and below water photographs of the fiber-optically tethered HydroRad buoy used for determining remote-sensing reflectance. The buoy is easily deployed from a small boat, or can be tethered to a moored HydroRad for time-series measurements of RSR.

Figure 3. Aerial photograph of the LSI study site for closure experiments. The red crosses show the locations of the HydroRad moorings.

Our modeling approach to interpreting bottom reflectance temporal variability and its relationship to surface remote-sensing reflectance involves both numerical computations with Hydrolight, and semi-analytical modeling for the inverse problem of determining bottom depth, reflectance, and water-column properties in optically shallow waters. Towards this goal, the simultaneous measurements of bottom reflectance and RSR with the HydroRad moorings has proven invaluable. It is also critical to the modeling approach to obtain simultaneous water IOP's, and again the IOP instruments on the HydroRad moorings have provided these valuable data. The moorings are designed to obtain a nearly complete optical dataset to perform closure, and thus test both the accuracy of the data and our ability to model it.

WORK COMPLETED

We have completed the development of a new oceanographic, hyperspectral radiometer system called the HydroRad. Six of these radiometers were built and deployed at LSI during the field campaigns on the CoBOP DRI. Extensive data were collected of spectral irradiance reflectance of sand, seagrass, and coral at a variety of locations around LSI. The HydroRads were configured to simultaneously measure remote-sensing reflectance with tethered spar buoys at the surface. In addition to the six HydroRads, we deployed six HOBI Labs a-beta and c-beta instruments, two HydroScat-2's, and a HydroScat-6. With these instruments we obtained extensive measurements of the water IOP's, simultaneously with the HydroRad radiometric measurements. All of the data have been processed and a metafile of our datasets has been prepared and posted on our website (http://www.hobilabs.com). Analysis of these extensive data sets has been a major on-going task and was the primary emphasis during this reporting period. Thus far three papers have been completed (Maffione, 2003, Maffione et. al, 2003, Stevens et. al, 2003) and two are currently in preparation. Results have also been presented at Ocean Sciences and Ocean Optics meetings.

RESULTS

Our moored time-series measurements revealed a strong tidally coupled variation in the water optical properties around LSI. Differences in the optical properties consistently differed by more than a factor of two between high and low tide, with the peak in optical properties at low tide and conversely at high tide. This variability in the water optical properties will certainly effect the remote sensing measurements and interpretation and should be taken into account in analysis and modeling. The HydroRad measurements of RSR revealed a correlation with changes in water optical properties, even where the signals were mostly dominated by bottom reflectance. Bottom reflectance measurements made with the HydroRads at various sites did not show any consistent variation in the spectrum with time of day, indicating that the reflectance spectrum of bottom types can be considered constant in modeling, and that biological changes due to solar intensity will be difficult to detect with remote sensing. In areas where bottom reflectance is high (e.g., sand), the reflectance of upwelling light at the water/air interface was found to have a significant effect on the apparent optical properties, severely complicating analytical modeling of optically shallow waters. Wave focusing was also found to be very problematic in making AOP measurements, but could be overcome with appropriate sampling strategies. Both our measurements and Hydrolight simulations revealed that K_d is a very poor approximation of K_{Lu}, having serious impact on published shallow-water optics models.

The moorings allowed us to collect continuous time series of the optical properties of the water as well as the light field over several days. After three to four days, each mooring was removed in order to recharge the batteries over night and clean the optical surfaces. Because the water was clear, optical

surfaces were usually found to be relatively clean. Then the mooring was redeployed the following day. Mooring turn-arounds were staggered so that there were always a few moorings deployed at any given time. Figure 4 shows an example time series of the water optical properties as measured by the a-beta and c-beta instruments. Note the nearly perfect correlation of the optical properties with the tidal cycle, as evidenced by the water column height. Figure 5 shows an example of the moored HydroRad measurements. These results are currently being analyzed in attempts to compare closure with computational solutions of the radiative transfer equation.

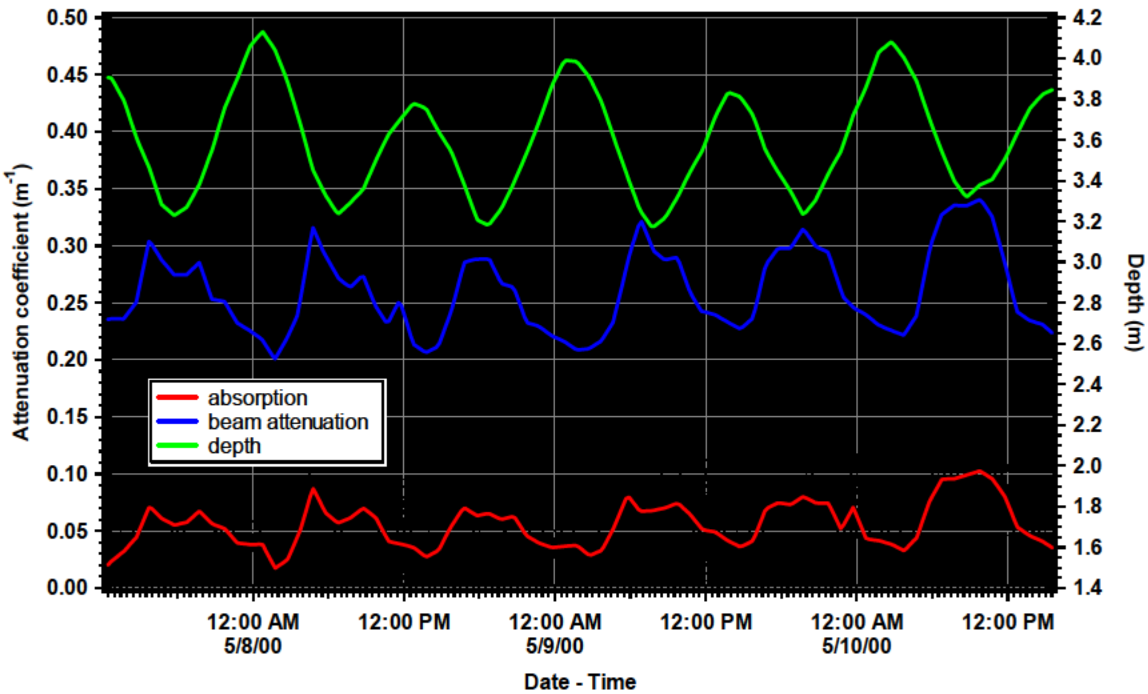

Figure 4. Moored time series of absorption, beam attenuation and water height measurements made with the a-beta and c-beta instruments at LSI. The variability has nearly perfect correlation with the tidal cycle.

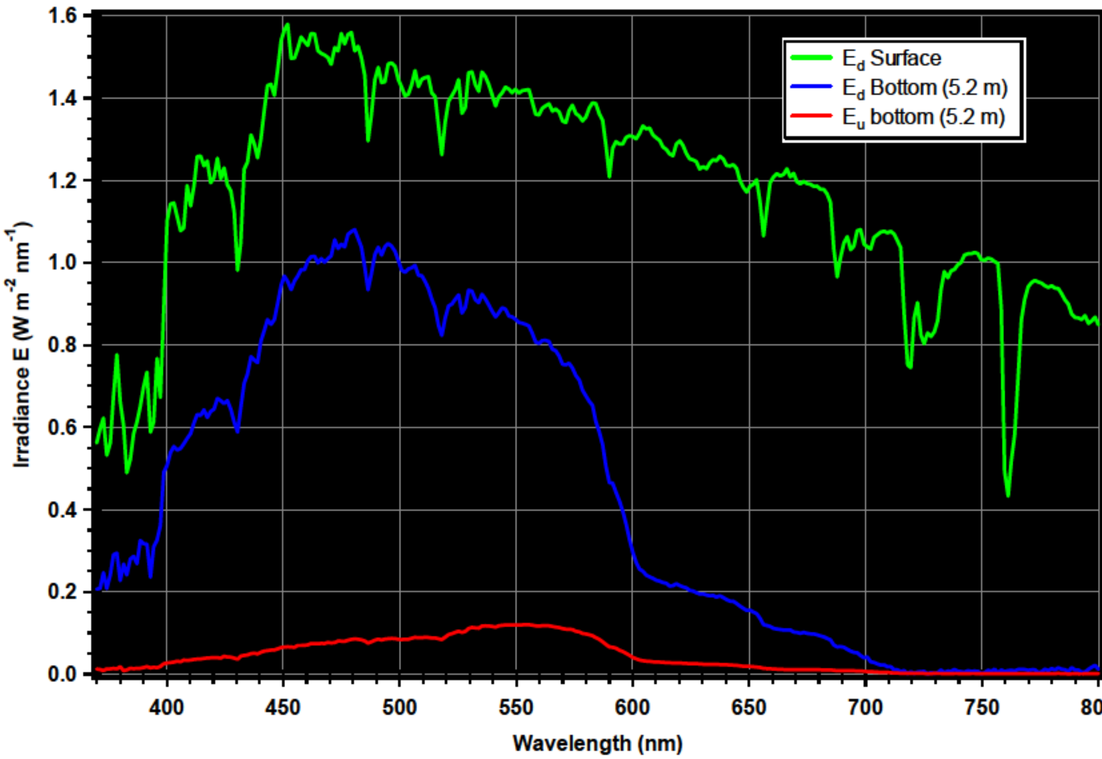

Figure 5. Graph showing example measurements from the HydroRad moorings. The green curve is the downwelling irradiance incident on the water's surface; the blue curve is the downwelling irradiance incident on the bottom; and the red curve is the upwelling irradiance reflected off the bottom.

IMPACT/APPLICATIONS

The development of the HydroRad hyperspectral radiometer provides a new, powerful and versatile tool in ocean-color remote sensing applications, especially in the study of optically shallow waters. Unlike the Satlantic hyperspectral TSRB, the HydroRad has four spectrometers that are coupled to rugged underwater fiber-optic cables. Moreover, the HydroRad is complete self-contained and easily operated from small boats or by divers, and it is easily moored. It is vital when measuring RSR in optically shallow waters that bottom reflectance is also measured. The HydroRad can perform both measurements simultaneously.

TRANSITIONS

The HydroRad is being used by Richard Zimmerman on the CoBOP program to study light propagation through submerged aquatic vegetation and the spectral reflectance signatures of seagrass. The fiber-optic cables and light collectors that we also developed in conjunction with the HydroRad are being used by other CoBOP investigators, including Charles Mazel, Pam Reid and Eric Louchard, and William Philpot. The HydroRad is now the primary radiometer used by the Monterey Bay Aquarium Research Institute and is mounted on three of their moorings in the Monterey Bay Sanctuary. They also have plans to mount HydroRads on the equatorial Pacific moorings funded by NASA. The HydroRad is being used extensively on ONR's HyCODE program, both at LEO-15 and

the West Florida Shelf. Other investigators who are now using the HydroRad to study both remote sensing and in-water AOP's are James Mueller at San Diego State University, Anthony Vodacek at Rochester Institute of Technology, Raphe Kudela at the University of California at Santa Cruz, and Mark Moline at California Polytechnic State University.

RELATED PROJECTS

My approach to measuring and modeling light propagation in optically shallow waters, developed on CoBOP, has successfully been applied in an Army Corps of Engineers study of the impact of dredging on seagrass communities in Laguna Madre. The measurements and modeling of light propagation in the presence of high concentrations of resuspended sediments was conducted by HOBI Labs under subcontract with Texas A&M University. This same approach was recently funded by the Environmental Protection Agency for HOBI Labs to study aquatic vegetation in Yaquina Bay, Oregon. Under subcontract with the University of Texas, HOBI Labs was recently funded to apply this approach in a new study on the impact of oil drilling on kelp in Prudoe Bay, Alaska. HOBI Labs is also using the HydroRad on two NOPP projects to study the Monterey Bay Sanctuary.

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Stevens, C., et. al., 2003. Effects of microalgal communities on radiance reflectance spectra of carbonate sediments in subtidal optically shallow marine environments, *L&O* (published).

PUBLICATIONS

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